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FLOW OF PARTICLES OF VARIOUS ENERGIES IN A ROTATING MAGNETOSPHERE

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[USSR]

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ABSTRACT

The mechanism of magnetosphere reconstruction during fluctuations in the solar wind is considered. Part of the lines of force of the magnetic field passes then from the core of the magnetosphere, bounded by the rotational sheath of the lines of force, intersecting the Earth at the 73° latitude, into the tail of the magnetosphere, or vice-versa, from the tail to the core. The existence is foreseen of peculiar closed electron sheaths with energies of several tens of kev in the tail of the magnetosphere, partially consisting in portions of sheaths of magnetic and partially of electric drifts. The latter prevails at magnetosphere boundary. Depending upon the energy of electrons, two types of sheaths are possible. Some close on the night side of the magnetosphere tail without enveloping the Earth (less energetic electrons), others encompass the Earth, closing on the daylight side of the magnetosphere in the transitional layer from the interplanetary plasma to the magnetosphere (higher-energy electrons). Depending upon the character of solar wind parameter variation, the electrons, stored in the tail, pass into the core and vice-versa. In the first case, the electrons partially fill the belt of electrons with energies of tens kev, and partially (with small pitch angles) run out along the aurora line (line of maximum aurora recurrence). The width of the aurora zones is determined by the thickness of the above-

* DVIZHENIYE CHASTITS RAZLICHNYKH ENERGIY VO VRASHCHAYUSHCHEYSYA MAGNITOSFERY.

mentioned transitional layer in the equatorial cross-section (Larmor radius of solar wind protons) and at projection on Earth it is found to be quite small.

* * *

1. - DYNAMICS OF LINE OF FORCE MOTION AND RECONSTRUCTION OF THE MAGNETOSPHERE DURING MAGNETIC STORMS

The variation of the magnetic field on Earth at change in the shape of the magnetosphere under the effect of solar wind is considered in [1] (still in print). It is shown in this paper, that the increase of the horizontal component of the magnetic field at low latitudes during the first phase of a magnetic storm is explained not so much by multi-lateral compression of the magnetosphere, as by the decrease in the degree of its stretchability toward the side from the Sun, that is by distance ratio decrease respectively at night and daylight boundaries of the magnetosphere. This ratio is in its turn determined by solar wind pressure p_d, directed from the Sun, to the isotropic hydrostatic pressure p of the wind and varies with the change of the latter. For example, during the first stage of a storm with sudden commencement, p_d / p decreases by comparison with the unperturbed value as a result of heating of the solar corpuscular flux by the shock wave from the Sun, and the magnetosphere becomes less stretched, while the horizontal component of the field increases in low latitudes on Earth. The consideration is conducted on the basis of the simplified model, proposed in [1], which coordinates the Bird method with the formal admission by (Ones)*

In the present note we consider another aspect of magnetosphere shape variation under the effect of solar wind fluctuations, and namely, the mechanism itself of line of force of the Earth's magnetic field reconstruction and of flow of particles with various energies, taking into account the rotation of the magnetosphere.- Themewise, the work [1] precedes the present paper [though it is still unavailable].

The variation of the character of solar wind and of the degree of magnetosphere stretching toward the night side entails the passage of

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[in transliteration]

the lines of force of the Earth's magnetic field from the day to night side and vice-versa. This process is clearly seen by considering the Fig. 1 a and б, where we figured the meridional, along the line Earth-Sun, and the equatorial cross sections of the magnetosphere. The lines OO' and OO" in Fig. 1 a and the line O'O" in Fig. 1 represent the cross sections of the boundary between two regions A and B, differing by the character of motion of the lines of force in the process of Earth's rotation.

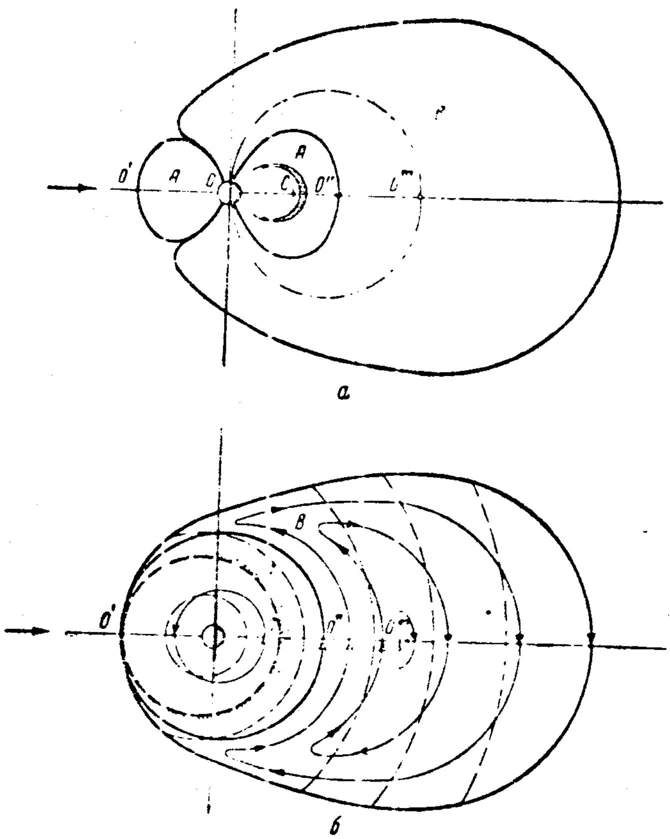

Fig. 1. - Meridional along the line Earth-Sun (a — view from the morning side) and equatorial (б — view from the North pole) cross sections of the magnetosphere.

The region A (core of the magnetosphere) stretches along the line Earth-Sun to points O' and O". The point O", about which the rotation of the lines of force of the region B takes place (tail of the magnetosphere) is projected along the line of force on the poles (dashes). The points O' and C are the points of equal intensity of the magnetic field; they determine the boundary of the equatorial cross section of the fast particles trapped in the core (energy >10 kev) with great pitch angles at the equator. Shown near C is the region of splitting along the sheath's pitch angles of the magnetic drift passing through O' from the daylight side. Moreover, presented in 1б are the sheaths of field line of force motion (solid thin curves). Arrows indicate the direction of motion of the lines of force of the field.

The region B is usually called magnetosphere tail or "coat". This is justified in models with very stretched magnetosphere, in which the region A is, for most of it, bare, and it is contiguous to the solar wind. In the model, demonstrated here, the lines of force, drifting to the night side of the magnetosphere in the process of their rotation with the Earth, pass also a significant part of the region from the daytime side of the magnetosphere, as this can be clearly seen from Fig. 1 б. The region B encompasses the region A almost to the midday point O', shielding the region A from a direct contact with the solar wind. In order to emphasize this fact, we shall conditionally designate the region B as the magnetosheath and the region A as the core of the magnetosphere.

The motion of field's lines of force is determined by low-energy particles of the magnetosphere plasma component; their drift in the electric field, induced in a fixed system of coordinates relative to the line Earth-Sun, prevails over the magnetic drift. The tying of the lines of force to Earth through the ionosphere leads to the fact, that in the equatorial region the rotation of the lines of force of the B-region takes place around the center O"' in a direction, opposite to that of line rotation of the core, as this is indicated by arrows in Fig. 1 . The core region is bounded by the surface of magnetic field's line of force rotation (sheath of particle electrical drift), these lines crossing the Earth's surface at the same latitude, passing through the points O' and O" respectively on the daylight and night sides from Earth.

Plotted in the same figures are the lines passing through the point C, cross section of the region of the energy component trapped in the core, and for which the magnetic drift prevails over the electric. The magnetic drift sheaths of energetic or fast particles are determined by the condition of preservation of the first and second adiabatic invariants and for particles with great pitch-angles they intersect the equator along a line, equal to the intensity of the magnetic field. Particles with small pitch-angles will drift along sheaths, outgoing on the night side somewhat farther than the sheath with great pitch-angles. The spitting of sheaths by pitch-angles is, however, insignificant in the real case. The splitting region of the extreme sheath of the core is marked by dots in Fig. 1, a and b.

Estimates for the model of ref. [1] give for OO'' a distance of $\sim 12\ R_E$ at $OO' \sim 10 R_E$, and $OC \sim 2^{-1/6}\,OO' \sim 7.9\ R_E$ or $3^{-1/6}\,OO' \sim 6.9$ depending upon whether the field at daytime boundary is doubled or tripled at perturbation by comparison with the unperturbed value for the dipole. At the same time the sheath of the electric drift, separating the core and the tail regions of the magnetosphere, cross the surface of the Earth along a circle with latitute $\varphi_0 = 73^\circ$, while the boundary of the core-trapped radiation (energetic component of the plasma), crosses the surface of the Earth along a line, tangent to the circle $\varphi_0 = 73^\circ$ at the midday point, and to the circle with $\varphi_1 = 68^\circ$ at the midnight point (see Fig. 2 б). This line (dashes in Fig. 2, б) can be identified with the aurora line, and the circle $\varphi_1 = 68^\circ$ — with the polar circle.

At variation of the character of the solar wind a redistribution of lines of force by regions A and B will take place. For the case of solar wind increase at constant dynamic-directed to hydrostatic pressure ratio, the magnetosphere will undergo a uniform compression without substantial redistribution of lines of force by regions A and B [1]. At the same time, the settling rate of the new state of the magnetosphere is determined by the propagation velocity of the magnetic disturbances. If, however, the hydrostatic pressure should rise more rapidly than the dynamic one (for example at passing of a shock wave), the stretching of the magnetosphere would decrease, and part of field's lines of force would have to pass from the tail to the core. At the same time, the circle φ_0 and the line of polar aurorae will shift toward the region of higher latitudes. The process of line throw-over is effected continually, and, as may be easily seen, it ought to take place sufficiently rapidly, in a time, comparable with the propagation time of the hydromagnetic disturbance. However, the final settling of the new equilibrium state can be delayed by the fact, that the lines of force of the tail may result azimuthally twisted from the night side, and a specific time, perhaps of the order of an hour from the moment of SC, will be required for the final transit of the "surplus" lines of force from the tail to the core. On magnetograms for classical storms with sudden commencement and sharply-expressed first phase, one may see, that following a sharp jump, the field pursues a somewhat slower growth through the beginning of the main phase. It is possible that this is ex-

explained by a lag in the transition of the lines of force from the tail to the core, rather than by further rise of pressure in the corpuscular flux.

At solar wind variation, attended by a rise of p_d / p, the magnetosphere elongates and the reconstruction proceeds in the reverse order. However, contrary to the preceding case, the transit of lines from the core to the tail region will not experience any lag, since obviously, the lines of force are less twisted in the core.

The motion of the lines of force at time of transitions between the regions A and B must induce currents in the ionosphere and provoke oscillations of the magnetic field on Earth, the amplitude of which, growing with latitude, possibly exceeding the mean effect of field variation during the storm. The development of a circular current, lowering the horizontal component on Earth at time of the main phase of the storm, at invariable solar wind pressure, symmetrizes somewhat the magnetosphere [1], leading also to a shift of lines of force from the region B into A. However, the effect of circle's $\varphi = 73^o$ shift into a region of higher latitudes is concealed by the considerably greater effect of line of force distortion by the ring current, leading to lowering of the latitude of the circle $_o$ and of the aurora region.

The assumption of the existence of viscous forces acting at magnetosphere boundary from the side of the solar wind, must lead to the representation of the presence of convective flow in the B-region [2]. Without taking into account the Earth's rotation the approximate pattern of convective shifts in the equatorial plane is drawn in Fig. 2 a. The direction of motion through the ionosphere of the lines of force, projecting the region B to the Earth's surface in the circle $\varphi = 73^o$, is marked by arrows in Fig. 2 б. The ionospheric currents, induced by line of force diffusion, are directed toward the opposite side [2].

The convective motion of such a character, whereby the field's tubes of force shift by latitude may be realized either in the case of forces acting from the side of considerably denser plasma than that of the magnetosphere, or the ionosphere, or in the case of entirely specific distribution of plasma pressure by magnetic sheaths. For example, for a dipole

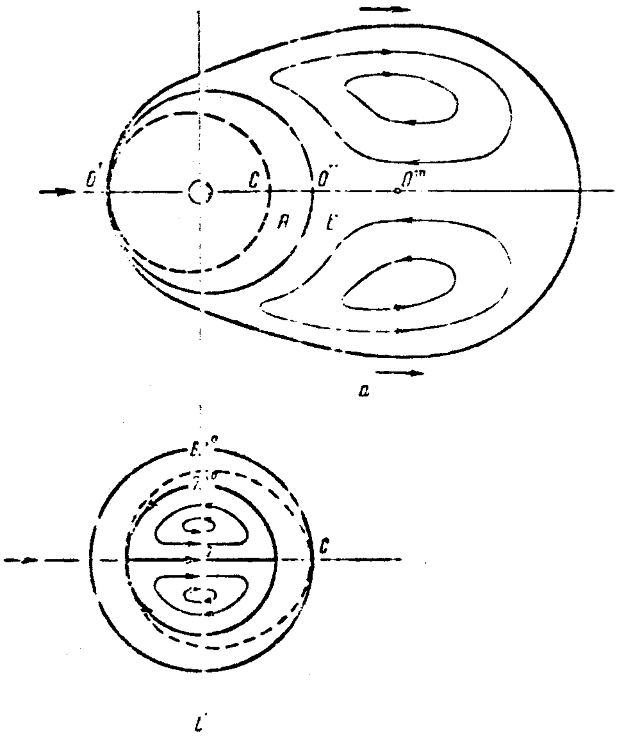

Fig. 2.- Motion in the equatorial plane of the lines of force of the tail, caused by hypothetical forces of viscosity at magnetosphere boundary, and projection of the B-region on the Earth's surface along the lines of force of the field in a circle of 73° latitude.

Arrows indicate the direction of line of force diffusion in the ionosphere. The ionosphere currents are caused by the latter flow in opposite direction. The dashed curve is the aurora line and the projection of the trapped radiation region, undergoing magnetic drift.

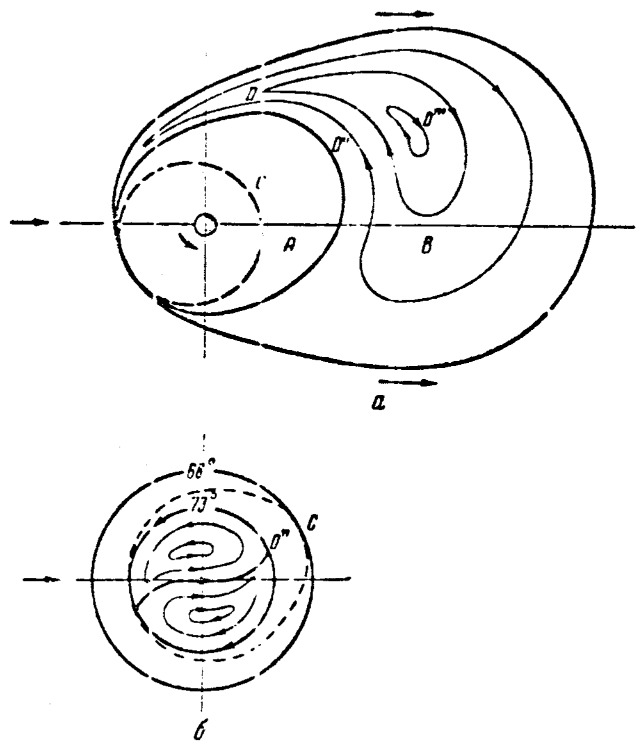

Fig. 3. - Same as in Fig. 2, a, б, taking into account the rotation of the Earth.

The rotation of the lines of force with the Earth is taken for the basic motion; the diffusion in the ionosphere is viewed as a disturbance.

field, pressure must drop with the parameter L of the magnetic sheath no slower than $L^{-20/3}$. In the tail of the magnetosphere the pressure drops much more slowly than at the dipole, while the pressure of plasma is comparable with the magnetic pressure. This softens considerably the condition of convection possibility along the latitude, and it is reasonable to assume the existence of such convection in the tail.

As to the region of the core of the magnetosphere, whose lines of force cross the Earth at latitudes $\varphi < \varphi_0$, the law of field variation with L is there near the dipole, while the pressure drop is knowingly weaker than L^{-7}. That is why the convective shifts in the core cannot materialize with the transition of lines of force by latitude (by spreading the direct convection along the latitude to lower latitudes, the authors of [2] ignore this fact). However, if forces of friction from the side of the solar wind do exist indeed, just as do the viscosity forces in the magnetosphere itself, the peculiar motion in the form of circular displacement of two neighboring tubes of force without substantial variation of latitude in each elementary event, must also spread to lower latitudes. At the same time, the resulting current pattern will be similar with that, obtained at direct convection along latitude.

The estimate of the rate of line of force diffusion along the ionospheric currents, which is found to be less than the linear rotation velocity of the Earth's surface, allows to consider the convective motions in the tail as a perturbation superimposed on the rotational motion. If the convective motion is induced by the friction force from the side of the solar wind, the approximate resulting pattern of motion in the equatorial plane will be such, as shown in Fig. 3 a, and in projection upon the Earth's surface, as in Fig. 3 б.

The shift of the rotation center O''' of tail's lines of force, and, alongside with it of the core region on the equator, of the aurora line and of the night boundary of the belt at Earth's surface from the night to the morning side may be understood if we conditionally apply the Bernoulli equation for the tubes of gas frozen-in in the equatorial plane.
On the morning side of the magnetosphere the rotation of the lines of force takes place in the direction of friction force action from the side of the

solar wind, and on the evening side — in the opposite direction. That is why during the motion of field lines of force with the magnetosphere plasma along the tube of flux from the point D in Fig. 3 б. in the direction pointed by arrows, the potential φ of the friction force in the region B drops monotonically, increasing by jump at the point D. According to the Bernoulli equation for the tube of flux of an ideally incompressible gas

$$\frac{v^2}{2} + \frac{p}{nm_p} + \varphi = \text{const} \qquad (1)$$

the drop of the potential φ and of the velocity v along the flux tube must be attended by a rise in gas pressure p, tending to redistribute the tubes of flux and the magnetic lines of force in such a way, that the sum of gas and magnetic pressures be constant along the equator cross-section, that is, by shifting the gas, and alongside with it the lines of force, to the morning side.

Certain considerations suggest, that such an asymmetry pattern relative to the direction at the Sun, manifest in particular in the shift of the aurora line from the night to the morning side, must appear not only as a result of hypothetical forces of viscosity, the substantiation of which involving difficulties and doubts, but also as a result of peculiar forces of inductional nature near the surface of the magnetosphere.

2. - ON THE POSSIBILITY OF EXISTENCE OF TRAPPED RADIATION IN THE TAIL OF THE MAGNETOSPHERE

We have seen that the sheaths of magnetic and electric particle drifts do not coincide (in a field induced by Earth's rotation). In Fig. 1 б and others, we denoted by points C and O" respectively the distances from the night side to two sheaths of different type, contiguous along the line of the obtained meridian at the extreme point O' of the core of the magnetosphere. For particles with pitch angles near 90°, the magnetic sheaths cross the equatorial plane along the lines of equal magnetic field intensity. From the night side beyond the line, passing through the point C, the lines of equal intensity B close at magnetosphere boundary (dashed curves in Fig. 1). The distribution of particles along different type sheaths is determined by the energy of particles, for the velocity of the magnetic drift is proportional to the kinetic energy, while in the case of electric sheath, it does not depend on energy. For the dipole field, the ratio v_E/v_B of the electric to magnetic drift velocity of particles with subrelativistic energies and 90^o pitch-angles is

$$\frac{v_E}{v_B} = \frac{30}{\varepsilon r_e}, \qquad (2)$$

where ε is the energy in kev, and r_e is the equatorial distance to the line of force in Earth's radii. For small pitch-angles ($\alpha \to 0$), this ratio is $1\frac{1}{2}$ times less. In the inner regions of magnetosphere core the field is nearly dipole. That is why the critical energy, dividing the particles by two different types of drifts, $\varepsilon_k \sim 3$ kev at $r_e \sim 10\,R_E$. It is greater near the daylight boundary of the core on account of the decrease of the radial gradient of the magnetic field. It is possible to show, for instance, that if the field, compressed by the solar wind at daytime boundary is twice greater than the dipole value, then we would have at the boundary $\varepsilon_k \sim 20$ kev.

For an idealized fixed model of the magnetosphere, the field of which is determined as the sum of two dipole fields, the formula (2) will remain approximately correct for the inner regions of the tail (to the center O''' of the retrograde motion of lines of force). This means that the critical energy in that region must be less than in the core. For a model, accounting for the rotation, this is not so. The redistribution of the magnetic field in the tail of the magnetosphere at the expense of plasma flow caused by Earth's rotation, strongly diminishes the field gradient. As a result, the ratio (2) no longer drops, even in the inner parts of the tail, and, to the contrary, grows with the distance from the Earth in the night side.

As to the outer (beyond the point O''') and, particularly in the near-boundary part of the tail, stretching to the daytime side into the region of the point O', the ratio v_E / v_B rises particularly strongly. This takes place because the velocities of the lines of force (that is v_E), passing near the boundaries of the magnetosphere, exceed significantly the velocities of the lines of force of inner regions. If the latter are determined by the angular velocity of Earth's rotation, Ω, the first ones are determined by the angle λ between the radius vector and the rotation point of line of force motion in the region B from the morning side and with direction at the Sun. The angular velocity of these lines would be of the order of $[(\pi-\lambda)/\lambda]\cdot\Omega$. for lines passing close to the boundary of the magnetosphere; the angle λ can be quite small. If forces of friction exist, the velocity of the near-boundary line of force from the morning side will become still greater.

On the basis of the above-said, one may expect that in the tail of the magnetosphere and, more particularly near the boundary, the critical energy ε_h' is higher than the energy ε_k in the core of the magnetosphere. This means that there is a region of energies $\varepsilon'_k - \varepsilon_k$, at which the electric drift will prevail in the near-boundary regions of magnetosphere tail for particles undergoing mostly the magnetic drift in the core. One may figure the existence in the region B of peculiar sheaths, consisting of areas with prevalence of magnetic (inner region of the tail) and electric (near-boundary) drifts. For electrons the magnetic drift sheaths (dashes in Fig.1) will bend out at Earth's rotation to the night side on the morning side and toward the day side on the evening one. Certain electrons of not too high energy, hitting the region with a strong electric drift near the morning boundary, will not succeed in reaching it in the process of the easterly magnetic drift, and will again hit, alongside with line of force, the region of magnetic drift prevalence at a certain point on the evening side, after bending round the night boundary of the magnetosphere, thus closing the peculiar quasistationary sheath.

The same electrons of higher energies, that may succeed in attaining the morning boundary of the magnetosphere, ought to egress from the magnetosphere, as would seem at first glance. In reality they will hit the boundary layer with a great regular field gradient normal to the boundary. The thickness of this layer is in any case of the order of the Larmor radius of solar wind protons, with energy of several kev. That is why it is sufficiently wide to retain electrons of several tens kev. Under the effect of magnetic field gradient normal to boundary in the boundary layer, the electrons must drift eastward, bypassing the magnetosphere along the boundary from the daytime side and forming another family of closed sheaths.

Thus, all the electron sheaths of the magnetic-electric drift pass along a narrow boundary layer of the magnetosphere. That is why, whenever there are trapped electrons in the magnetosphere tail, the radiation intensity in the boundary layer must be significantly greater than in the inner parts of the tail. One may also figure an accelerating mechanism, acting upon the electrons at specific conditions in the process of their motion along a closed cycle within the framework of preservation of the first and second adiabatic invariants. Estimates show, that the closed electronic magneto-electric drift sheaths may exist for electrons with energy $\leqslant 100$ kev. At acceleration they will gradually transit into the core, completing the destruction of electron belt particles.

There exist no analogous closed sheaths for protons. First of all, protons cannot be thrown at the night side of the magnetosphere, for their magnetic drift is directed toward the side opposite to electrons, and, hitting the region of a strong electric drift at the evening boundary of the magnetosphere, they will drift westward. Secondly, reaching the magnetosphere boundary in the process of magnetic drift, protons cannot be retained by the boundary layer, for it is too narrow for them.

The magnetosphere reconstruction in time of magnetic storms, described in paragraph 1 and expressed in the variation of relative dimensions of the core and of the tail at the expense of the corresponding transit of the lines of force from one region to the other, will also lead to electron transition from the core to the boundary region of the tail and vice-versa. In the last case electrons with energy $\mathcal{E} \gtrsim 10$ kev, considered as "slow" for the B-region, since the electric drift prevails in some areas of the tail over the magnetic, pass to discharge of "fast" ones for the core. Here they will undergo a magnetic drift near the sheath, projecting to Earth along the aurora line (dashes in Fig. 2 δ, 3 δ). Those of them in which the pitch angle is sufficiently small, will run off into the atmosphere, as in the transition process to closer sheaths; the reflection points of particles are lowered. The small thickness of the boundary layer of the tail ensures the narrowness of the aurora region along the aurora line.

The confirmation of the drawn pattern of behavior of electrons with energy of several tens kev can be found, in particular, in the results of the study of intensity distribution and of the boundary region of these electrons on "Explorer 14". In Fig. 4, borrowed from [3] and representing the mean pattern of the distribution of the lines with equal intensity of electrons with energy >40 kev, for many flights, the bending of sheaths toward the night side is clearly seen, when approaching the morning side of the belt's boundary, coinciding with that of the magnetosphere. According to the idea expounded, this part of the sheaths belongs already to magnetosphere tail and the rotation of the sheaths toward the night side is explained by the influence of the electric drift.

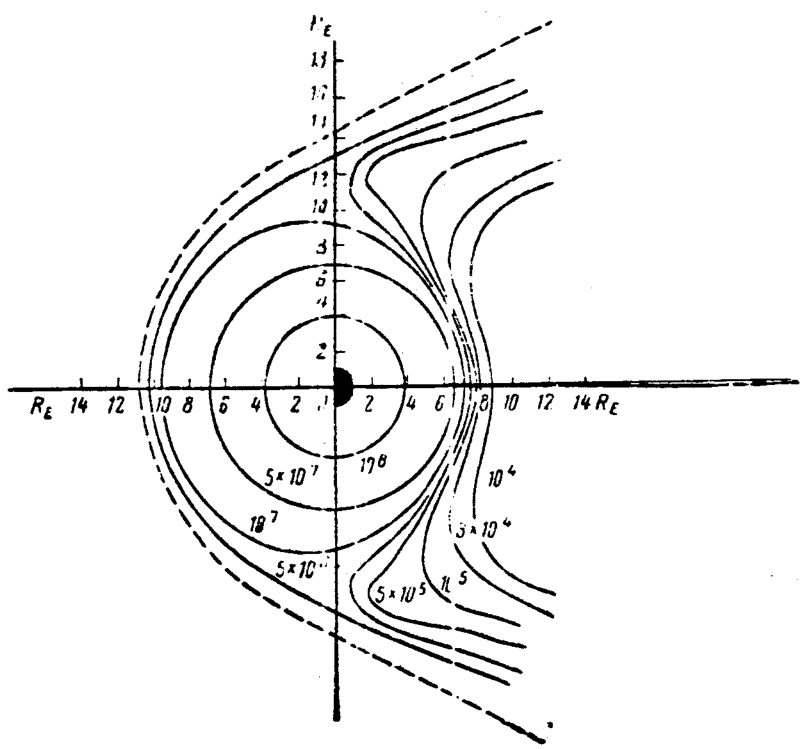

Fig. 4.- Equatorial distribution of lines of equal intensity of electrons with energy 40 kev (borrowed from [3]).

The fact that the daytime boundary of electron belts with energy of several tens kev always coincides with the boundary of the magnetosphere as if the distance from Earth to that boundary remained invariable, is is quite demonstrative. Except for the variation of solar wind parameters, case in which the dynamic to hydrostatic pressure ratio p_d / p remains constant, any distance variation to daytime boundary must be attended by the transition of the lines of force from the core to the tail and vice-versa. At the same time, since the intensity of electrons with energy of several tens of kev hardly varies, they effect the transitions alongside with the lines of force. If the tail could not not serve as a reservoir, preserving if only the electrons "squeezed out" of the core at its decrease, the belt of these electrons would be broken, upon magnetosphere expansion, over distances smaller than the magnetic field, which was never observed.

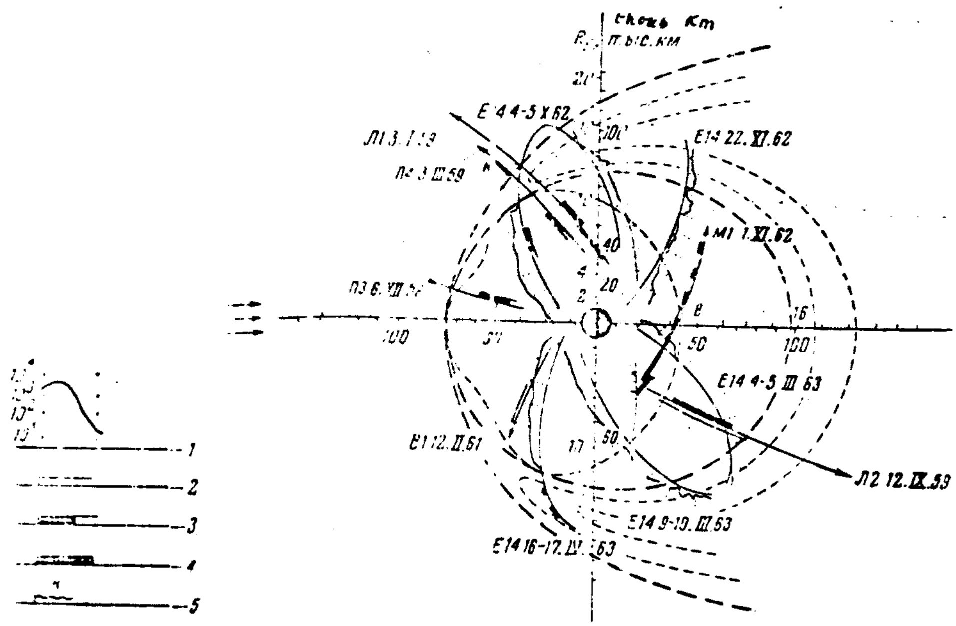

Fig. 5. - Coincidence of data on the basis of various published works on electrons of various energies.

The trajectories of satellites and rockets are projected on the equatorial plane along the lines of force of the dipole field. Data for Explorer 14 were borrowed from [4]. Plotted are the lines dividing the magnetosphere into characteristic regions (region of the electron belt with energy >40 kev boundaries between the core and the tail of the magnetosphere; dashes denote the projections of line of force motion in the tail of the magnetosphere).

Denotations : Л1, Л2 — Lunnik 1 and 2 (1st and 2nd Soviet cosmic rockets); M_1 — Mars 1; B_1 — Venus 1; П3, П4 — Pioneer 3 and 4; E14 - Explorer 14; The intensity of electron flux with $\varepsilon \gg 40$ kev is obtained by multiplying the counter readings (213 A) by 10^3. 1 — electrons $\geqslant 40$ kev (counter 213 A) 2 — electrons $\gtrsim 50$ kev (FEU); 3 — electrons $\gtrsim 1.6$ Mev (302); 4 — electrons 0.2 — 40 kev; 5 — primary cosmic rays.

The authors of [3] plotted the lines of equal intensity of the evening side in Fig. 4 in the assumption of symmetry relative to the direction at the Sun. What the real position is remains obscure. If we start from the considerations of paragraph 1 and from those, expounded here, there should be no total symmetry. From the data borrowed from [4], the only ones available to us, and which refer to flights of Explorer 14 toward the evening side of the magnetosphere, we plotted them on the composite Fig. 5. They allow no specific deductions. The approximate boundaries of characteristic regions of the magnetosphere are plotted in this Fig. 5. In particular, one may see, that upon vanishing of electrons with energies above 40 kev, they reappear beyond the night boundary of the belt (though with lesser intensity) in the boundary region between the core and the tail of the magnetosphere.

***** THE END *****

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REFERENCES

[1].- V. P. SHABANSKIY.- Kosmich. issledov., 3, No. 4, 1965 (in print)

[2].- W. I. AXFORD, C. O. HINES.- Can. J. of Phys., 39, 1433, 1961.

[3].- L. A. FRANK, J. A. VAN ALLEN.- E. MACAGNO. -J.Geophys.Res. 68, 3543, 1963

[4].- L. A. FRANK , J. A. VAN ALLEN.- Preprint to be presented at the Symp. on the results of the IGY.- IGC, UCLA., August 1964

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